Microwave Photonic Filter Using Multiwavelength Brillouin-Erbium Fiber Laser

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***Abstract*—A microwave photonic filter based on multiwavelength Brillouin-erbium fiber laser (BEFL) is proposed and experimentally demonstrated. By precisely controlling the output channels of the BEFL, the 3-dB bandwidth of the filter spectrum can be adjusted at a resolution of ∼24 MHz. The free spectral range of the filter can be tuned by changing the Brillouin gain fiber of the BEFL in addition to changing the length of the dispersion fiber, which adds flexibility to the filter system.**

***Index Terms*—Optical fiber lasers, nonlinear optics, filters.**

I. Introduction

MICROWAVE photonic filtering provides an attractive means of processing microwave signals in optical domain due to numerous advantages offered, such as low loss, high flexibility over large bandwidth and immunity to electromagnetic interference [1]–[4]. In addition, tunability and reconfigurability of the frequency responses are possible, which is of great interest to many researchers. Recently, various works on microwave photonic filters (MPFs) based on multi-source have been reported. Such MPFs provide a better solution in terms of stability due to incoherent operations of the laser systems, thus eliminating possible optical phase interference at the output. Different implementations of multi-source MPFs have been proposed, including the use of independent tunable laser diodes [5], spectrum slicing of broadband optical source [6]–[8], the use of multimode Fabry-Pérot (FP) laser [9]. However, it is impractical to implement MPFs using laser arrays due to high system costs incurred in order to realize high number of optical taps. For spectrum slicing, low power levels and high amplitude noises are the main drawbacks. Meanwhile, using FP lasers as optical sources limit the tunability of the filters due to difference in mode power distribution. There are several reported MPF structures whereby multiwavelength fiber lasers are used as optical sources, such as semiconductor fiber laser [10] and erbium-doped fiber laser (EDFL) [11]–[13].

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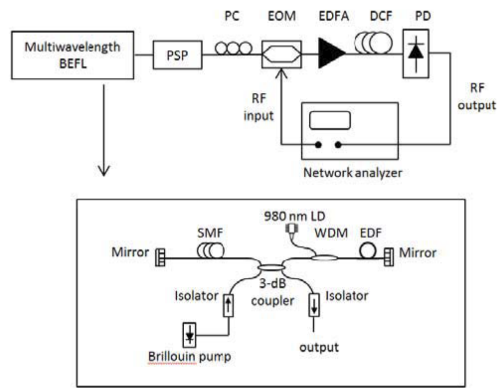

Fig. 1. Schematic of the filter with multiwavelength BEFL as optical source.

In this letter, we demonstrate, to the best of our knowledge, the first MPF based on multiwavelength Brillouin-erbium fiber laser (BEFL). BEFL structures operate at the linear gain of erbium-doped fiber amplifier (EDFA) and Brillouin gain in optical fiber to realize multiwavelength lasing. As long as the optical power for a given wavelength exceeds the low Brillouin threshold of the Brillouin gain medium (BGM), a Brillouin Stokes signal which is ∼10 GHz frequency downshifted will be generated. The generation of multiple channels laser is realized from the cascaded Brillouin effect, in which lower order Stokes signals are amplified by the EDFA to initiate higher order Stokes signals. The number of lasing channels in BEFL can be easily controlled by adjusting the pump power that is used to pump the erbium doped fiber for precise controlling of optical taps. Since the wavelength spacing of 0.089 nm between adjacent channels is very small in this case, fine adjustment of the filter selectivity can thus be achieved. For free spectral range (FSR) variation, using different Brillouin gain medium results in different wavelength spacing, which in turn changes the overall FSR of the filter. Such feature, in addition to changing the length of dispersive medium, provides extra flexibility to the MPF system.

II. Experimental Setup and Principle

Fig. 1 shows both configurations of the proposed MPF and multiwavelength BEFL adopted from [14]. The BEFL consists of a 5 km length of standard single mode fiber (SMF) and a

10 m length of EDF, confined in between two Faraday mirrors. A 980 nm laser diode was used to deliver pump power to the EDF. A tunable laser source as the Brillion pump (BP) was coupled to the cavity via a 3-dB coupler. Tuning the EDF pump power adjusts the number of output wavelengths accordingly, whereas varying the BP wavelength changes the output wavelengths of the laser. The output of the BEFL was connected to the programmable spectral processor (PSP) so that the spectral profile of the BEFL can be modified. The PSP employed is the Lamda Commander (OSP-9100 Programmable Spectral Processor from Newport) with the capability of fine spectra shaping. Such device can also be replaced by a properly designed fiber Bragg gratings (FBG) filter. The BEFL output was then externally modulated by the radio frequency (RF) signal from a network analyzer using an electro-optic modulator (EOM). The flat gain region of an EDFA was utilized to ensure linear amplification of the modulated signal before it was sent through a dispersive medium, which was a 23 km dispersion compensation fiber (DCF). The DCF has a chromatic dispersion of about −245 ps/nm/km, which gives a total accumulated dispersion of −5635 ps/nm. The transmission spectrum of the microwave photonic filter was then investigated by the network analyzer after an optical-to-electrical conversion was performed with a 70 GHz photodetector (PD) (XPDV3120R from u2t).

Assuming the polarization state in the fiber system is optimized, the magnitude of the frequency response $|H(f)|$ of the filter is given by [5]

$$|H(f)| = R\cos\left(\frac{\pi\lambda_0^2 D}{c}\frac{f}{2}\right)\left|\sum_{n=1}^{N} P_n e^{-j\cdot 2\pi f\cdot(n-1)\cdot D\cdot\Delta\lambda}\right| \quad (1)$$

where R is the photodetector responsivity, λ_0 is the central wavelength, D is the total dispersion of the dispersive medium, N is the total number of optical carriers, P_n is the optical power of tap n and $\Delta\lambda$ is the wavelength spacing between adjacent wavelengths. The FSR is given by [11]

$$FSR = \frac{1}{D\cdot\Delta\lambda} \quad (2)$$

According to Eq. (1), we could see that the filter frequency response $|H(f)|$ can be manipulated by adjusting the number of optical taps through P_n and also the optical tap spacing $\Delta\lambda$. In our case, the multiwavelength BEFL design based on nonlinear stimulated Brillouin scattering (SBS) process, is capable to produce arbitrary number of Stokes lines by properly controlling the gain of the EDFA and Brillouin pump power. The spacing between Stokes lines is dependent on the germanium concentration of the Brillouin gain medium [15]. Thus by using different type of fiber, the Stokes line spacing can be manipulated, i.e. different $\Delta\lambda$ at the output of BEFL, which in turn causing variation of the FSR. On the other hand, the selectivity of the filter is related to the total number of optical taps, i.e. the number of wavelengths of BEFL output. Therefore, by controlling the number of optical carriers generated from the laser system, the selectivity of the filter can be tuned accordingly.

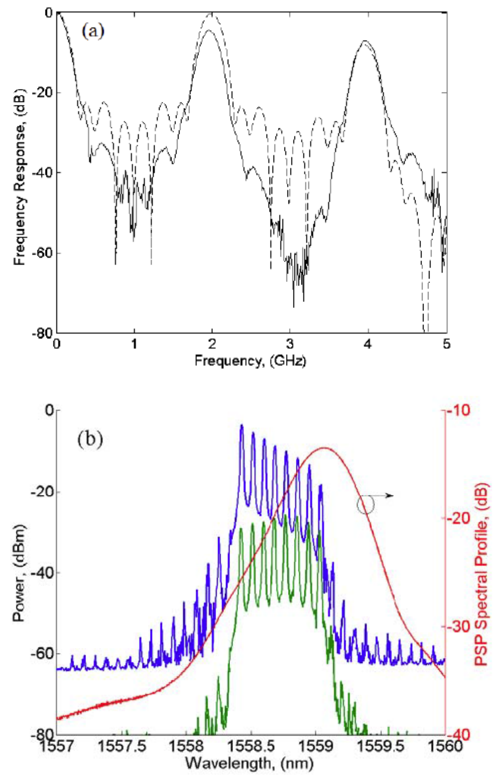

Fig. 2. (a) Simulated (dashed line) and experimental (solid line) response of the filter and (b) optical spectrum of multiwavelength BEFL before (blue) and after (green) the PSP. The spectral profile of the PSP is shown in red.

III. Results and Discussion

Fig. 2(a) shows a typical transfer function of an 8-tap transversal filter ranging from 10 MHz to 5 GHz. Fig. 2(b) depicts the original optical spectrum generated by the BEFL, before and after passing through the PSP. The PSP was programmed to obtain flattened BEFL Stokes line (the spectral function is shown in red in Fig. 2(b)). The Brillouin pump wavelength and power used in the experiment were 1558.4 nm and 3 dBm respectively, whereas the EDF pump power used was 205 mW. A baseband resonance was observed due to amplitude modulation scheme used in the setup. The normalized tap weighting for each optical carrier was [0.47, 0.56, 0.62, 0.83, 1, 0.84, 0.62, 0.42]. An FSR of ∼1.99 GHz was observed, both experimentally and theoretically. The main to secondary sidelobe ratio (MSSR) of the filter is better than 20 dB because of the windowing effect introduced by the PSP. Good agreement between the simulated response (dotted line) and the experimental response (solid line) was obtained.

The number of Stokes wavelengths at the output of BEFL is dependent on the EDF pump power. Fig. 3(a) shows the relationship between normalized frequency responses centered at ∼3.95 GHz with different number of BEFL channels.

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